Newsletter for July 2023

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ARF update: simulations and constraints

By Lathreas | July 29, 2023

Hello again! I have some new updates with regards to the Anatomy Re-engineering Framework (ARF for short), which again is meant to be a tool for us to design novel anatomy in a physically accurate and surgically feasible manner.

Last time, I talked about some new 3D representations of muscles we implemented, that should allow us to simulate their stretching and compression faithfully during editing, so as to prevent these tissues from clipping through each other. This is of course very important to be able to get an accurate representation of the complete anatomy — all tissues take up space, and we must know in detail how much space essential parts take up to be able to aesthetically modify the shape of a face to look, say canine, feline or draconic.

Beyond the effects of volume, the physical interactions between tissues has an important effect on the function of them. For example, blood vessels or vascularized tissues that strongly compress against other tissues can lead to a cut-off of blood flow, which has consequences ranging from unpleasant to disastrous. Similar concerns exist for nerve tissues, which must not overstretch or snag during movement.

Optic nerves as an important test case
An excellent example of this is the optic nerves, which connect the eyes to the brain. The position of eyes on the face is one of the most important determinants of a satisfactory appearance. The optic nerves are flexible, and freely move as your eyes move, but presumably would need to be longer if we were to move eyes further forward and laterally on the face. For planning of technical methods, e.g. how to operate around the nerves, and to anticipate just how much longer the nerves need to be while preserving

^ Reference photograph of a real wolf.

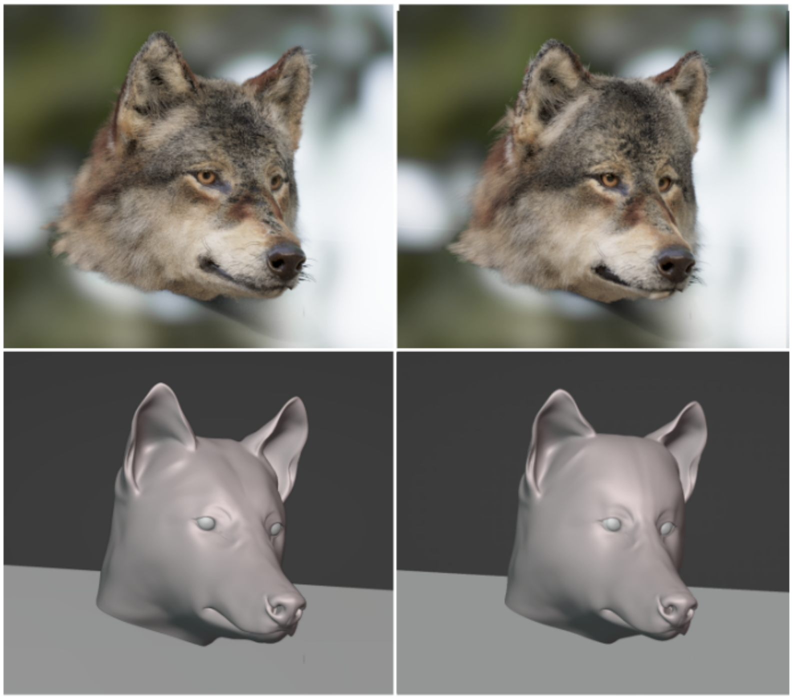


Figure 1 (above): 3D anthro wolf head models with simulated fur. An unaltered human skull (from CT scans) was embedded in each model to determine the relative position of the eyeballs and to wrap the skin around. **(left)** 3D model with braincase constrained to the human size, but no eyeball position constraints. The eyeballs have been moved forward and sideways from its default human position, to place them at the characteristic position seen in real wolves. Indeed, the optic nerve must stretch significantly to accommodate the new eyeball positions, and the orbitals must be (surgically) repositioned as well. **(right)** Model with braincase constrained to the human size, as well as eyeball positions constrained to the human default position with respect to the brain, which as such are contained within the orbitals of the unaltered human skull (not shown). In this case, proportionally, the forehead appears much larger, and the eyes appear to be much closer together than in real wolves.

your full field of vision, we need to build a model.

Optic nerves must be lengthened for a satisfactory appearance

In some of the extensive modeling we have done throughout the past year, we have discovered that for most anthropomorphic facial anatomies, such as anthro wolves or anthro dragons, the interocular distance (distance between the eyes) is essential for proper appearance. You can see this visualized in figure 1.

In principle, the further we can move the eyes apart and forward, the better. This necessitates stretching the optic nerve further than its default length over time, requiring care to avoid injuring the tissue. Nerves in general do have the capacity to stretch over time when a constant force is applied, and optic nerve lengthening has been reported in scenarios where the pressure between the eyes and the brain was altered (Wåhlin et al., 2021). However, there is a limit to the speed at which we can apply this lengthening, as well as which forces we can apply, before nerve damage occurs. As such, we must balance the exact amount of optic nerve lengthening we want to aim for in our anatomic designs.

These sorts of balances between aesthetics and feasibility occur for any tissue we want to change, including muscles, bones, and so forth. If any anatomical change requires gradual lengthening or reduction of tissue size, the ARF should explicitly report that that is the case, so that we know that we need to develop or apply certain technologies to correctly change the tissue's size in a patient without any surprises (such as methods that use "braces" of sorts, or in advanced scenarios, techniques that promote tissue growth through the use of molecular signals, and so forth). A user should also be able to constrain the length, size, or shape of a certain tissue to prevent it changing — a good example of that would be the brain, which we do not want to alter in any scenario.

Soft body modeling of optic nerves

These concerns must all be taken into account, which we can do by using some sort of soft-body dynamics to properly emulate how soft tissues, like muscles, take up space and interact with the surrounding tissues.

To begin small, I have implemented a simple simulator for the optic nerve consisting of Hookian springs (i.e. springs that have a linear response, and as such are the simplest to implement), to constrain the length of the optic nerve. Because I can, at least at first, represent the optic nerve as a one-dimensional cable, this allows me to implement and test the basic principles that I can later apply on 2D (skin) or 3D (muscles) tissue representations!

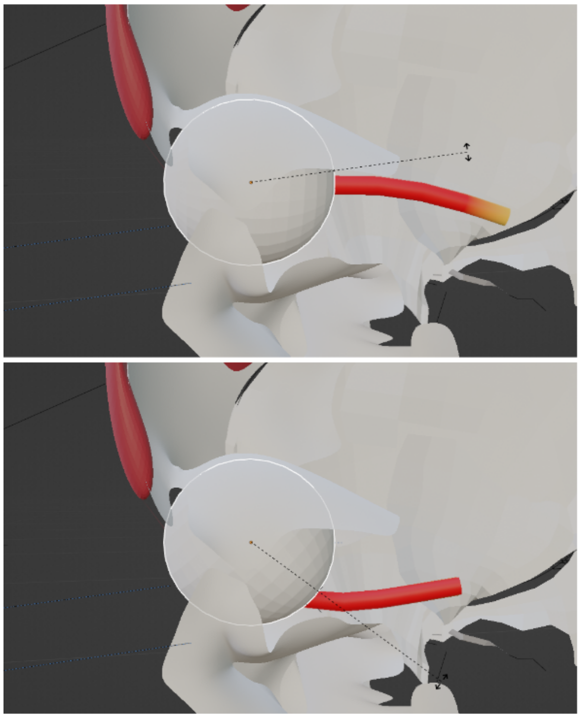


Figure 2: Constraint-based editing of the eyeball, where the optic nerve follows along while preserving length. The colors represent the strain on the tissue. (Strain is a measure for how much the cable stretches.) We'll next try to implement this in 2D and 3D tissues.

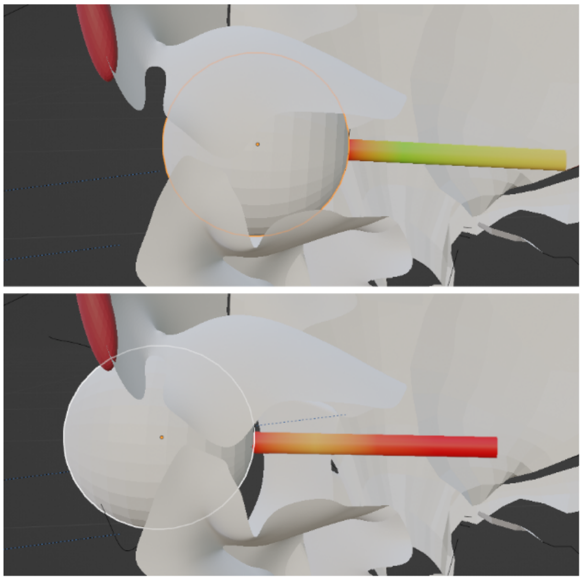


Figure 3: Moving the eyeball works as well. The colors indicate how much strain the system is currently experiencing, which is a transient effect until the system reaches equilibrium again. Since the root of the optic nerve is not yet constrained, it moves along. Note that the strain is not uniformly distributed. This is a transient artifact of the simple method used to calculate the Hookian spring deformations, and disappears once equilibrium is reached. It may not have too big of an impact on editing itself, but for operations requiring more accuracy, switching to a Lagrangian approach would solve this artifact.

Some limitations of the proof of concept method

This simple proof-of-concept is powerful enough to do some simple editing, and will converge to the right result. However, with this method, you are still allowed to move something beyond the constrained parameters. The algorithm has to try to get back within the constraint limits after each edit, and that can potentially lead to transient accuracy issues when more complexity is added, as is seen in figure 3. A much better approach would be to use Lagrangian constraints. It's hard to summarize this method in a single sentence, but in Lagrangian mechanics, you transform the coordinates of the system into so-called generalized coordinates that represent all the possible conformations of the cable that you can have without breaking any constraint. That way, no matter how you move it, you cannot move beyond any constraint and the system doesn't have to catch up. As you might imagine, though, this method is a lot more mathematically involved due to the many weirdly shaped constraints that the system has. Depending on the need, I may implement that better method some time in the future, though that will of course take time.

The future

Now that I know that this simple proof of concept simulation works, I can implement more sophisticated constraints and also look beyond, to 2D and 3D tissues. I have already experimented with both topologies, but I will need to do some additional work to ensure that the vertex ordering is correct, so that each vertex connects to the correct neighbor during simulations. I will also work on the dependency graph, and ensure that changes to key constraints will propagate to changes to the surrounding anatomy. For example, when the user moves the eyeballs, it should also move the orbitals along with it and block as soon as a constraint is violated, so that the user doesn't need to worry about all that. Fun stuff ahead!

References:
Wåhlin A, Holmlund P, Fellows AM, Malm J, Buckey JC, Eklund A. Optic Nerve Length before and after Spaceflight. Ophthalmology. 2021 Feb;128(2):309-316. doi: 10.1016/j.ophtha.2020.07.007. Epub 2020 Jul 10. PMID: 32659310.

For more information, you can always refer to the ARF project page at https://freedomofform.org/research/project-3d-anatomy-cad/ - enjoy!

Strategy and roadmap update

By Zennith | July 25, 2023

As you know, we're especially excited about making non-human identity affirmation procedures a reality. But which ones?

What exactly are our technical goals, and how will we achieve them? For several years, we have been hesitant to commit to a few major decisions. In some cases, we weren't sure how feasible some things were, and in others, we simply weren't sure how to scope and prioritize the projects. We know how impactful a procedure would be for a patient, and some of the decisions we are making are essentially triage of who we can help first. We held off until we were sure.

Now, we have settled on a specific goal we feel comfortable defending: **anthropomorphic procedures reaching patients within 30 years (by 2053)**. Nothing less, and nothing more. **Our research schedule prioritizes work on craniofacial, integumentary, tail, and eye changes** because they are expected to be most rate-limiting.

Note that separate, standalone changes (such as permanent tail modifications) will implicitly be pursued, but for long-term strategy purposes, we are aiming for a procedure where all changes come together into one whole.

This information is presented as two substantive new additions to our website: (1) a complete replacement of our strategy and vision page (uploaded July 5th), that includes a whole-organization view and lightly touches on technical detail, and (2) a more detailed writeup of our 30-year technical roadmap. (Links to these pages are also at the end of this article for your convenience).

The rest of this article goes into more detail about how we got here, and where our technical thinking is currently.

How our thinking has changed:
In 2018, we provided a first pass on answering those questions (re: our technical goals, and how to achieve them) in general. Starting to figure out how to accomplish a wide range of identity affirmation procedures, using any combination of techniques, ranging from neuroprosthetic and surgical to bioprinting and genetic methods.

Since then, we've learned, grown, and advanced. Many concepts have stood up to time, though of course some haven't. We've become much more opinionated about some technical choices, and have realized that others don't matter as much right now. We've prioritized some goals, and deferred others until later, intending to optimize how we use our resources over time. We are driven to reach uncompromising and fulfilling full-body affirmation procedures well within our lifetimes.

In late 2021, we set out on an effort to write hundreds of pages of documentation across the body. It seemed like a good idea at the time, but honestly, we got bogged down in detail with things that were not particularly insightful. The documentation we were writing had little bearing on subsequent decisions, or weighing which projects we should prioritize. The planned outcome was originally a “list of parts”, not analysis - and this was a silly idea in hindsight. (When several highly energetic and motivated creatures start procrastinating something, that is a warning sign!). Nevertheless, we came away from the effort with better knowledge of anatomy, as well as several analyses by accident - which turned out to be the things we actually needed anyway!

Analysis of the anatomy and how to change it. Judgment of the sorts of changes that can believably become safe and tractable. Thinking about how to get both sensory and motor innervation, from snout to tail-tip - and trying to work within the existing nervous system as much as possible, to minimize the amount of “new information” that has to be hooked up to your brain. And, crucially, considering questions about whether certain body parts could even be modified without unacceptably affecting other ones nearby. We learned a ton - just not what we expected to learn!

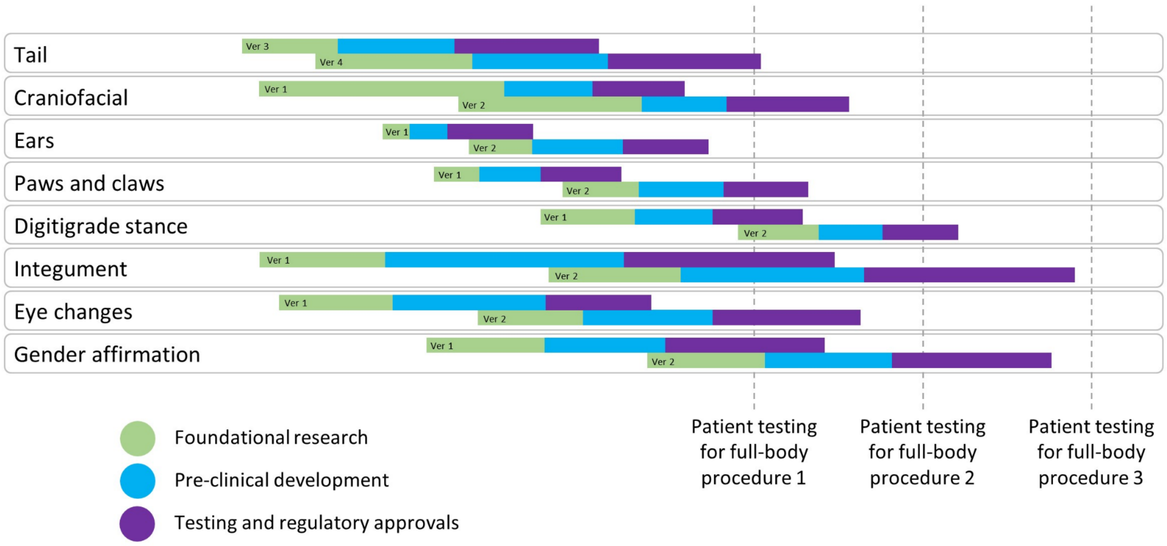
As well, a couple years ago, we naively started with the idea that discussions of anatomy as well as technical method should be connected in the same breath. We had anticipated having several chapters of the documentation be dedicated to anatomy, and an equally long set of chapters be dedicated to the technical methods. The thing is, there are so many options to fulfill almost any anatomical goal, and methods are changing so rapidly, that it was looking like a silly exercise.

For example, if someone gets a tendon surgically repaired or replaced, it might be with a new, non-biologically-sourced material, it might be an autologous transplant, or it might be an acellular implant of extracellular matrix. The decision might depend on the patient’s age, the specific tendon being repaired/replaced, and even what the surgeon feels more comfortable with. It would not be helpful for our organization to decide we would use one or another method to create new tendons 10 years from now; the decision is neither impactful nor likely to be correct.

As a second example: Just think about how far the concept of genetic vectors has come in the past 5 years! Specific choices, such as deciding whether to use Adeno-Associated Viruses, Lipid Nanoparticles, or other options, would be premature.

Arriving at the technical roadmap:
The point of a roadmap is to target a specific goal, identify the major challenges, and plan how to work through them. The issue is that

Research outcomes needed for full-body procedures, prioritized by anatomical region



you can't just start with a goal and work backwards. You have to work through the whole development path to reach the goal, to make sure the goal is actually reachable - or otherwise, adjust as needed. Essentially, all critical risks of the roadmap have to be resolved simultaneously, so that you aren't blindsided in 10 years.

We looked for an overlap between 3 competing forces: (1) a timeline of 30 years from now (2053), (2) anatomical and physiological feasibility, and (3) a conceivable path to develop any new needed technical methods. We wanted to aim for something that was achievable, but sufficiently comprehensive for full-body procedures. Aiming for something too difficult could stretch our organization too thin, whereas setting our sights too low would risk creating a set of technologies that are incapable of coming together into a unified, satisfying whole.

We weighed goals along a range of difficulties, from "just" aiming for tails, through anthropomorphic forms, through quadrupedal forms and creatures with wings.

Anthropomorphic forms seemed to hit the sweet spot in difficulty. There were several questions that stood out as challenging, but fundamentally tractable.

But one question stood above the rest, as to whether or not anthros would be our goal: can you get a nice snout/muzzle shape without impinging upon the braincase? If you can, you're in business! If you can't, you're looking at innovating new neurosurgical interventions, which could push anthros outside of the 30-year timeline, nudging us towards a less-ambitious goal instead. The answer, thankfully, was yes, you can get a nice snout/muzzle shape without touching the braincase (see our June 2022 newsletter).

Another head-related question was: could creatures, especially canid ones, get ears appearing correctly on top of their heads? That answer also turned out okay. Interestingly, canines including dogs have a "vertical canal" portion of their outer ear. The vertical canal is a tube starting just outside their middle ear, connecting upwards to the floppy external portion of their ear that you can see on top of their head. It's like a snorkel for sound. Dogs have their inner/middle ears in essentially the same place that humans do. Using the same, bioinspired strategy would let anthros with canid-like appearances have ears on top of their head, without very challenging surgery to move their inner/middle ears.

After analyzing other regions in the body, we judged that no other anatomical region presents a similar level of risk. Getting a new tail to be both physically integrated and innervated has multiple solutions that are obvious to us. Changes to the skin - making fur, scales, or feathers - would take tissue and genetic engineering, but in a highly regenerative part of the body that is extremely accessible to manipulation. Getting digitigrade footpaws, to be a bit flippant, is glorified orthopedic surgery! That's not to say that these modifications would be easy or without concern; just believably tractable.

So yes. Anthros it is.

Further details click into place fairly easily. Four anatomical regions stuck out as being rate-limiting for making anthros possible: craniofacial anatomy, integumentary/skin changes, cosmetic eye changes, and creating tails. We deferred working on a few other anatomical regions because they could be akin to carving a pedestal rather than focusing on training an allegorical monkey.

The last big piece of the puzzle was deciding how to schedule work on each individual anatomical region. There's really only two options: work on everything as a tightly coupled monolith, or aim for more independent parts that are iterated and versioned. In the latter case, even if a newer, better version of an anatomical modification is delayed for some reason, you can still get a full anthropomorphic procedure accomplished, and make a big difference in someone's life. You can guess the decision we made on this one!

The roadmap in a nutshell:

- We've selected anthros as our 30-year goal.
- We have selected work on craniofacial, integument, eye, and tail anatomy as the highest priorities (work has already started).
- Work on forelimbs, digitigrade hindlimbs, gender affirmation, and the external portion of ears will begin later, in approximately 5-10 years, depending on region.

It's important to note that we intend to continue supporting and developing additional products that are independent of full anthropomorphic procedures, such as temporary prosthetic tails, or standalone permanent tails. While our main goal with them is admittedly technology development for anthros, we are enthusiastic about any technologies that help with identity affirmation. (Similarly, we would not stop doing anthropomorphic procedures simply because we develop quadrupedal procedures in the future - just aiming for a challenging goal doesn't mean we don't want to do relatively easier things too!)

We are sufficiently confident in this plan to present it publicly, and have already been using it for internal planning purposes. Still, as with any plan, remember that it will change over time. That's really all there is to it! More details are on our website at the links below.

In the future, we hope to provide more detailed feasibility discussions as they pertain to our technical roadmap. But we're not going to promise hundreds of pages of documentation - we've been down that road before! Naturally, as we learn more from our research in the coming months and years, we will use what we learn and adjust the timeline as needed. When we do, we'll let you know.

More detail:

- Strategy and Vision
- Technical Roadmap
- June 2022 newsletter with the craniofacial discussion

PS - Yes, this roadmap is a big deal for our organization. But, it's intentionally the second article in this newsletter. Pontificating is easy. Results, such as those in Lathreas's article, are ultimately more important - such results are why we're even bothering with this planning!